ROLAMITE FUNDAMENTALS

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N76-19442

INTRODUCTION

The first speaker of the symposium, John Ford, holds responsibility at Sandia Laboratories for development of rolamite devices. His presentation began with a history of rolamite's development, and proceeded to a discussion of inherent features and capabilities. While pointing out the breadth of applications for the rolamite design, Ford also detailed some basic constraints and limitations of its use.

The text and figures which follow are taken directly from Ford's discussion of a series of 35 mm slides designed to give participants a review of the rolamite mechanical design concept.

HISTORY AND DEVELOPMENT

Rolamite was invented at Sandia Laboratories in Albuquerque by Don Wilkes, whom you will hear later in the program. Don was working on a miniature velocimeter at the time he came across rolamite. He was trying to develop a very small first-integral device (Figure 1) employing a lot of new techniques for miniaturization, such as photochemical processing.

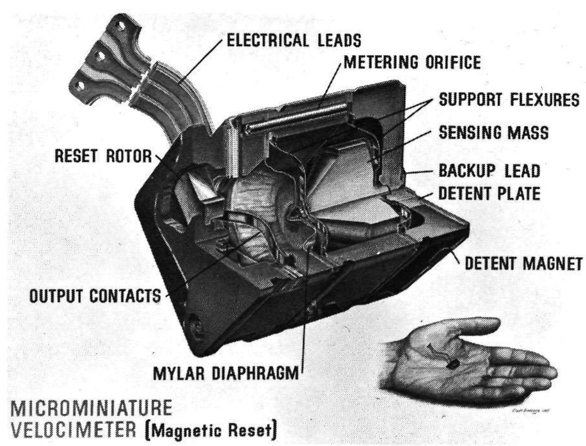

Figure 1

Don was having trouble with the sensing mass, which moved under an inertial load. He could not obtain sufficient displacement of the sensing mass with the suspension system he was using, and he also had some trouble supporting it under side loads. Here we see the system he was using (Figure 2), with the sensing mass, and these are the flexural supports, which had to move in and out as the mass moved.

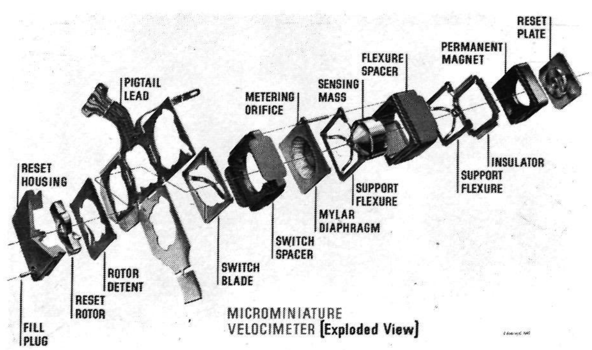

Figure 2

Under the inertial load, the mass had to move the support members out (Figure 3). He was getting very little excursion of the mass and was having some side-load support trouble.

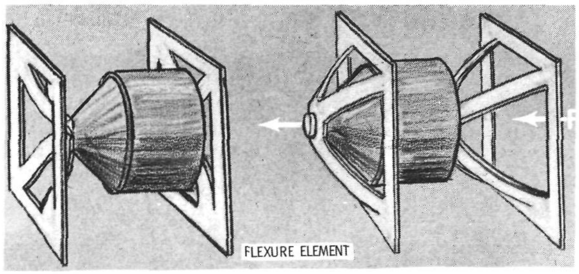

Figure 3

In an effort to get more excursion and better support he happened across the idea of using a thin piece of metal foil bent in an S shape (Figure 4). He found that the band would move very freely back and forth in the X direction but that the side-load support was practically nil in this configuration.

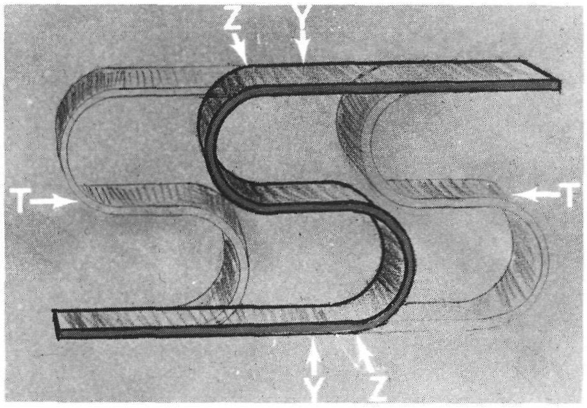

Figure 4

He next inserted a couple of rollers into this S shape (Figure 5); he not only continued to get good movement back and forth but also had started stiffening the whole system.

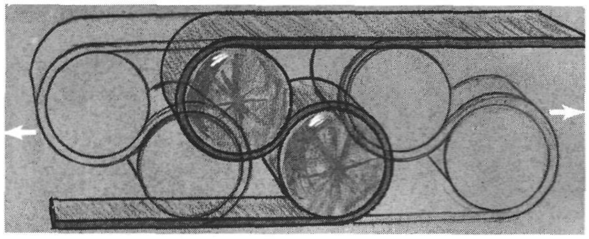

Figure 5

Putting this basic configuration into a case (Figure 6), he found that he had satisfied most of the requirements. The more he started looking at the unique aspects of the geometry, the more he discovered that he had something quite practical and quite new. This, then, is how the concept originated.

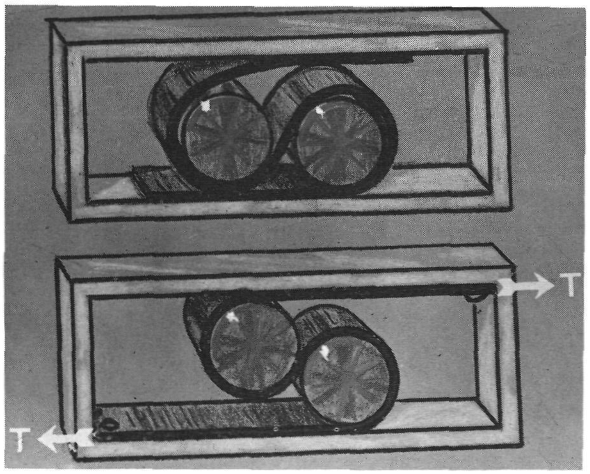

Figure 6

SUSPENSION SYSTEM FEATURES

Now I would like to talk about some of the features of the rolamite suspension system. First of all, as we said, with this particular geometry you get very free movement back and forth in the X direction (Figure 7).

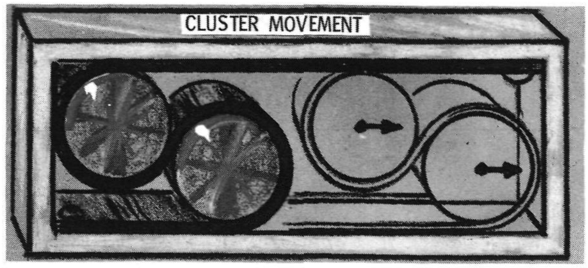

Figure 7

The angle of repose (Figure 8), or the line connecting the centers of the rollers, always maintains the same angle regardless of the location of the roller cluster along its travel. The rollers counterrotate with respect to each other. When they move to the right, the back roller rotates counterclockwise and the front roller clockwise (Figure 9), and they would be just the reverse were they traversing to the left.

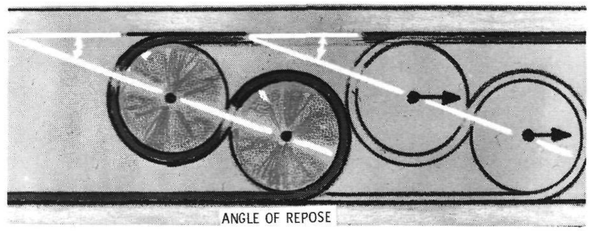

Figure 8

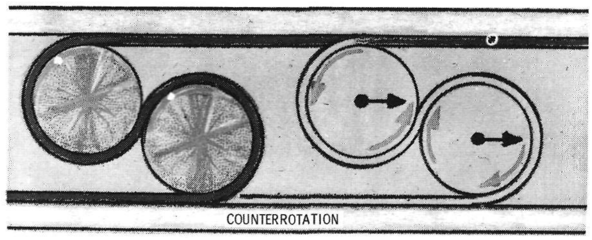

Figure 9

LOW FRICTION FEATURES

One of the two unique things about rolamite is its low friction; here we try to explain why. If you take a point A on the roller and a point A on the band, as shown in Figure 10, the two points will always stay together as the cluster moves. Since there is no relative motion between the band and the roller, there is no sliding friction. The friction is pure rolling friction, which is an order of magnitude less than that of conventional miniature precision roller or ball bearings.

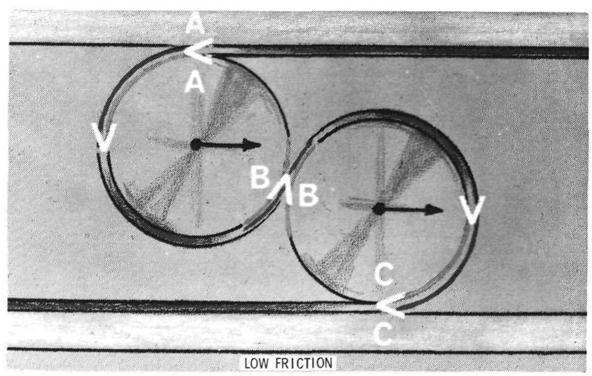

Figure 10

Figure 11 shows some typical friction values that we have measured in some experimental work at Sandia, and you will note that this happens to be for one particular geometry where the rollers were 1/2 inch in diameter and 3/4 inch long, using a beryllium copper band. With various thicknesses of band material, from 1/2 mil up to 2 mils, you will note that the coefficient of friction varies from about 0.0002 to 0.0007.

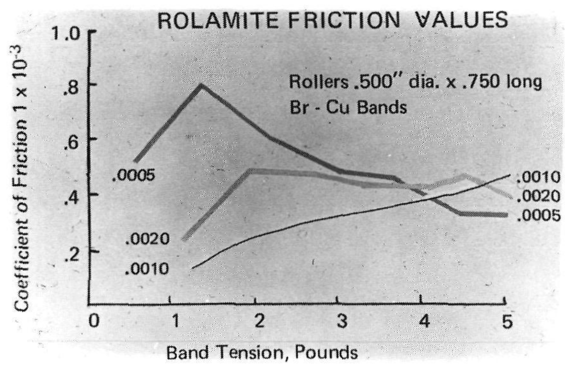

Figure 11

DISPLACEMENT FEATURES

Another feature about the geometry is that the surfaces will always remate once they are displaced from each other (Figure 12). Take a point A on the roller and a point A together on the band and move the cluster so that they will separate; when you move them back, the points will always come together again. This is important because we have found, in testing rolamite configurations, that the coefficient of friction actually decreases with continued wear. By always coming back together, the parts tend to accommodate each other. If there are any imperfections in the band or in the roller, or any contamination, they will wear in together, and continued operation will result in less friction, contrary to what can be expected in most mechanical devices.

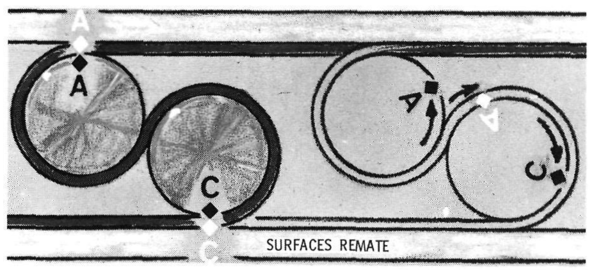

Figure 12

The cycloidal action of the rollers is unusual and gives rise to certain applications. If you have a point A on the band and a point A on the roller, the black, diamond-shaped part will show the trajectory of the point on the roller, and the point on the band will be on the white path as shown (Figure 13). This feature should make for a good dial indicator or speedometer or something of that kind, because a very small lateral movement will give a large sweep of a pointer.

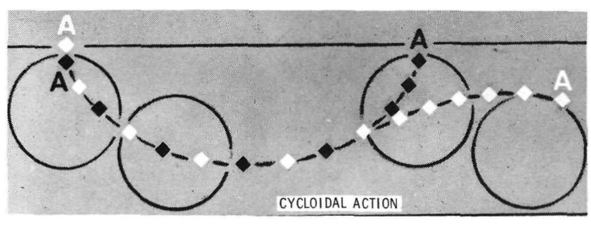

Figure 13

FORCE FEATURES

Now, I would like to discuss briefly the forces in the geometry. The first force is the tension applied to the band (Figure 14) to pull the cluster together.

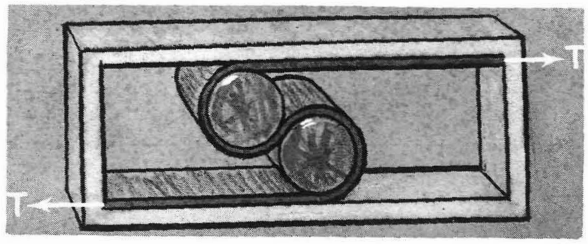

Figure 14

This creates a normal force between the roller and the band, and the band and the case (Figure 15). Taking moments around either of these two points, you will see that the normal force times the distance between the centers of the rollers is equal to the tension in the band times the guide surface spacing: the normal force is equal to the tension of the band times the guide surface spacing over the distance between the centers of the two rollers. This works out to be a very important relationship in figuring out many designs.

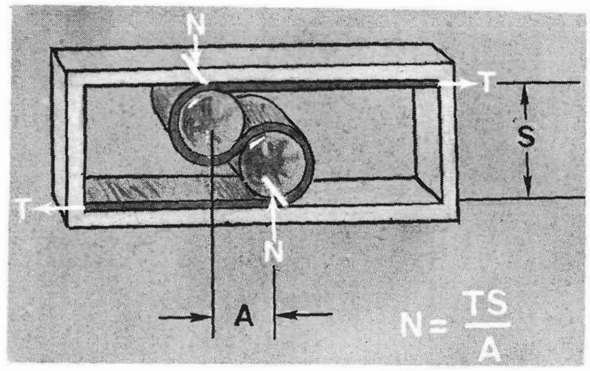

Figure 15

This merely shows that there is a resultant force created by the tension and the normal force, and this is illustrated in Figure 16 by R connecting the contact points of the rollers and the band.

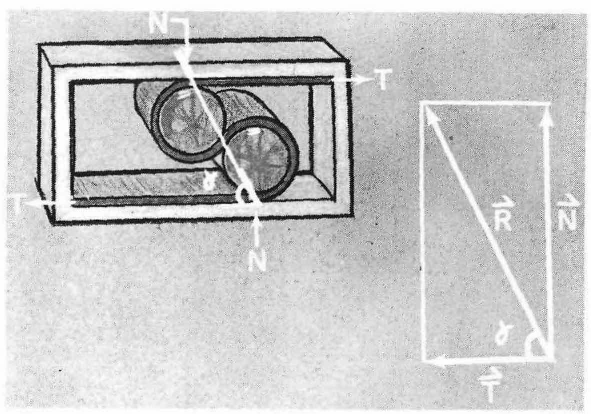

Figure 16

SIDE LOADING

Now let us consider the side-load support. First (Figure 17), in the Y direction we have two conditions (Figure 18), one when the side load is less than the normal force, the other when the side load is greater.

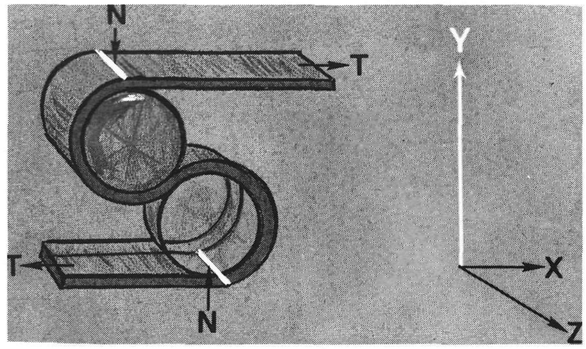

Figure 17

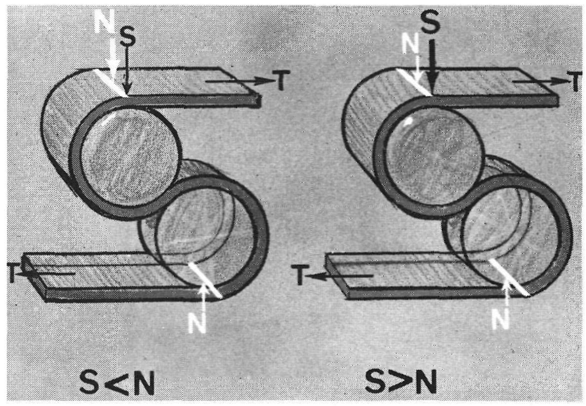

Figure 18

When it is less (Figure 19), the normal force at A will increase, the normal force at C will decrease by the same amount, and the load on the geometry therefore remains constant. There is no roller movement--and no problem.

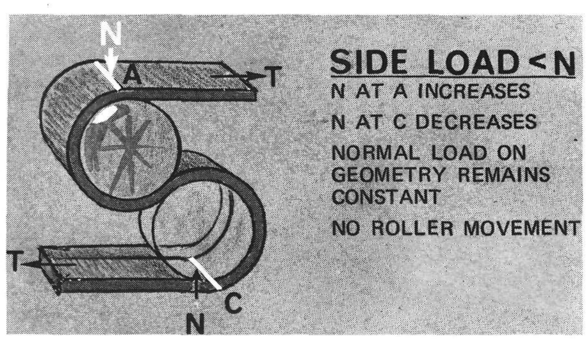

Figure 19

However, when the side load is greater than the normal force, the roller cluster will be deflected (Figure 20), but only as long as the force is applied. Once the force is removed, if you have not yielded the band, the rollers will snap back to their original position. However, if the side load is of such magnitude that you yield the band, then you do have problems and you must therefore design against this condition.

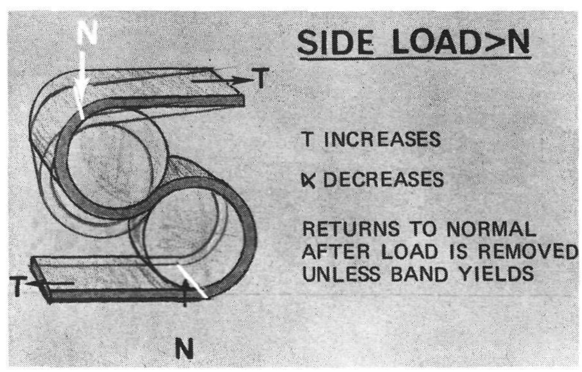

Figure 20

In the Z direction (Figure 21), you get some support from the friction between the rollers and the band, but it is minimal for most applications. In most designs, you have to introduce some friction to give you side-load support in the Z direction.

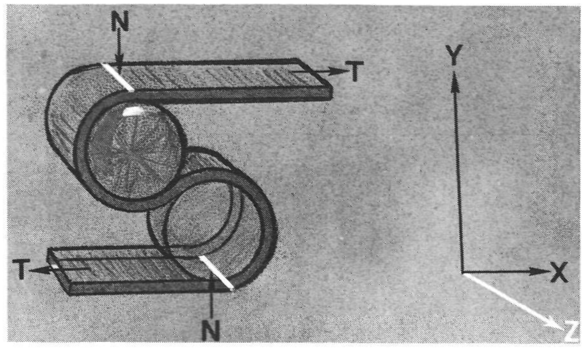

Figure 21

Figure 22 shows several of the many ways of doing it, and a relationship indicating that a good design exists when you can keep X less than 1/30th of the radius of the roller.

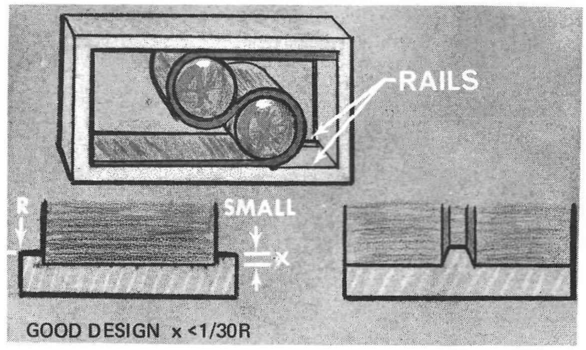

Figure 22

DESIGN CONSTRAINTS

The constraints on the geometry are really quite obvious. Naturally, you have to limit the thickness of the band to be compatible with the diameter of the roller. Figure 23 illustrates an unacceptable relationship and a more normal situation. Again a formula has been derived which says that if you keep the thickness of the band less than the diameter of the roller times the yield stress of the band over the modulus of the band material minus the yield stress, a good relationship between roller diameter and band thickness exists. The next illustration (Figure 24) shows constraints on guide surface spacing with respect to roller diameters and band thickness.

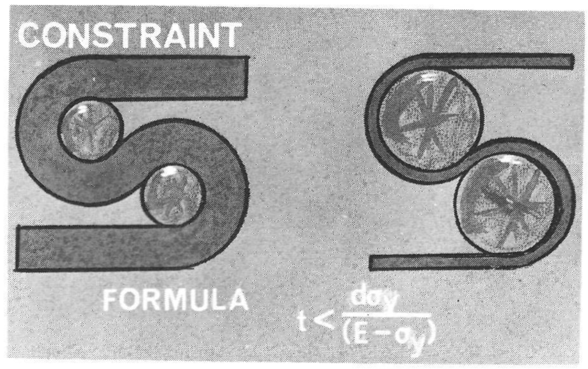

Figure 23

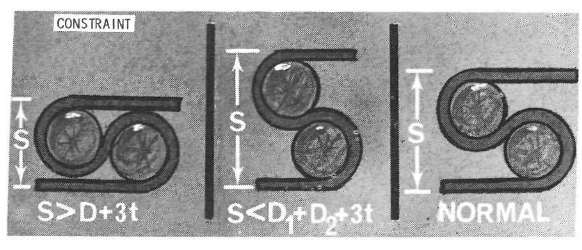

Figure 24

DESIGN FLEXIBILITY

I would like to point out a few of the things that we believe make rolamite fairly flexible for design purposes. One technique available to the designer is to vary the tension in the band (Figure 25) between a very loose and a very tight geometry.

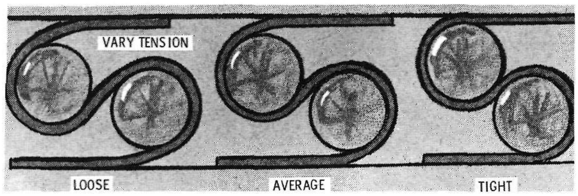

Figure 25

One of the advantages of the loose geometry (Figure 26) is an ability to roll over obstacles such as contamination, lint, or things of that nature that might get between the parts.

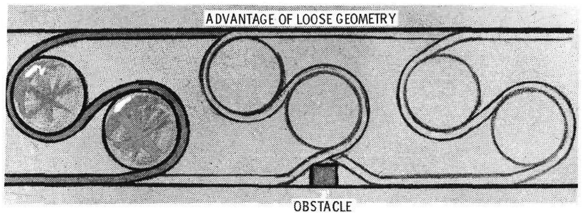

Figure 26

Another thing you can do (Figure 27), given constant guide surface spacing, is to vary the roller sizes and thus change the angle of repose. In each case shown in Figure 27, you will notice that the angle of repose is getting steeper. Therefore, the real variable is the angle of repose.

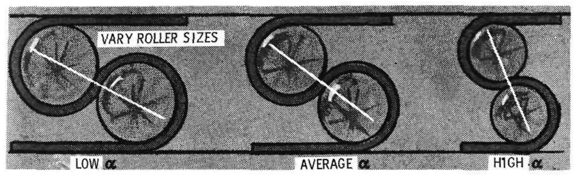

Figure 27

Combining the tension in the band and the angle of repose we have a factor we call compliance (Figure 28). Low band tension and shallow angle of repose result in a very compliant geometry, whereas high band tension and steep angle of repose result in an uncompliant geometry. A very compliant geometry might be useful when you have very small forces to make the cluster move. Or you might have limited travel available but large forces, and would in such a case make the geometry less compliant. You can design to best suit your own situation.

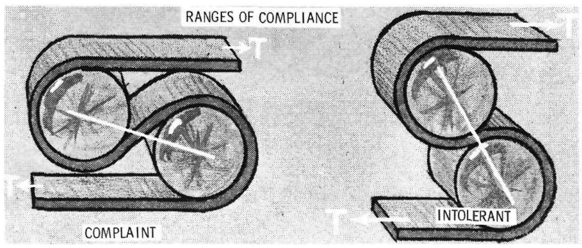

Figure 28

Another thing you can do (Figure 29) is have different roller sizes. The two cylinders need not be of the same diameter. You can use hollow tubing or dumbbell-shaped rollers as shown in Figure 29. If you want a detenting action, you can use flat or cam-shaped rollers.

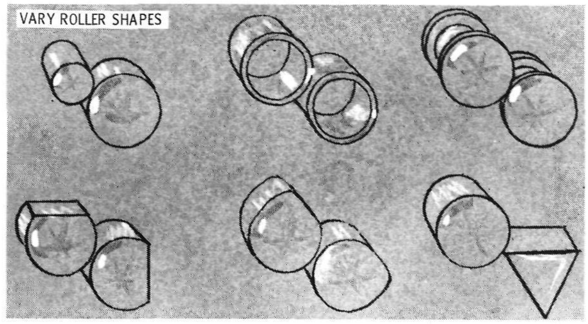

Figure 29

Still another thing you could do is to vary the guide way to provide features that you might like. By putting a groove in the guide surface (Figure 30), you can provide a detenting action, and with a ramp you can provide energy level detenting. With this expanded case you might want the rollers to move down and spring out and provide a latch, or provide some forces in the Y direction. If you want some very peculiar type of curvilinear motion, you might want to design your guide way as shown in Figure 30. Thus, variation in the roller guide-way configurations can provide certain unique design features.

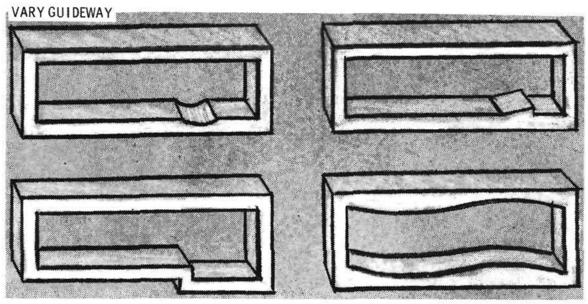

Figure 30

FORCE GENERATION

The next series of slides has to do with the force-generation capabilities of the rolamite geometry. As I said earlier, I think there are two unique things about rolamite. One is the low friction, the other is the ability of the geometry to create forces without additional parts. This may be the most difficult thing to understand, and it will be treated later in great detail by Dick Cadman, but I want to prepare you for his analytical analysis.

If you have a thin metal foil and bend it between your hands, it will assume an S shape, as shown in Figure 31.

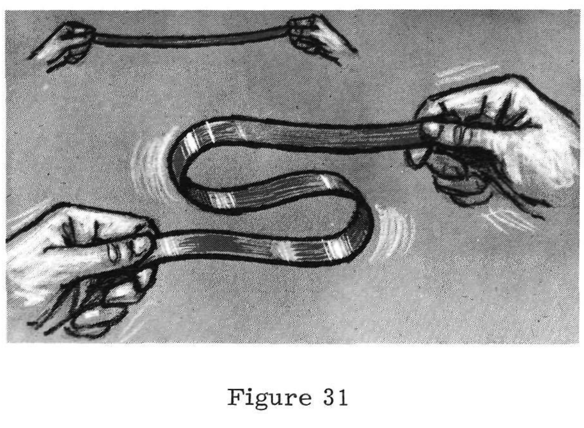

Figure 31

It will then take a force by one of the hands to move it out of that shape. If you notch the foil, it will want to assume the position shown in the blue (Figure 32) and will have created a force *to the right in assuming this position.* To get it back to the original position would require a force from the man's hand. This really is what happens when we notch bands or change the band configuration in rolamite. The whole force generation capability is brought about by the capability of the band to store elastic strain energy. The area of importance is the working area between points A and C.

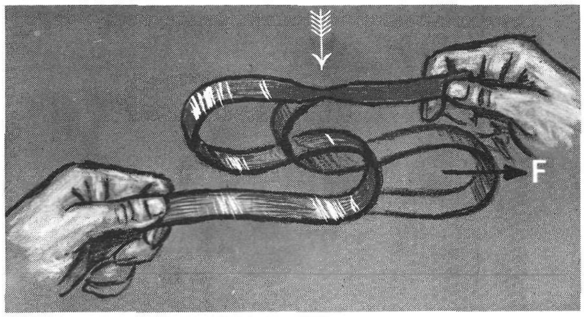

Figure 32

Figure 33 shows a mathematical relationship for the total elastic strain energy in the band between points A and C. This is a general equation which integrates the strain energy in each incremental length of the band times the stress and strain of the band at a distance, y, from the neutral axis of the band times band width. This defines the elastic strain energy available in the band at any one time.

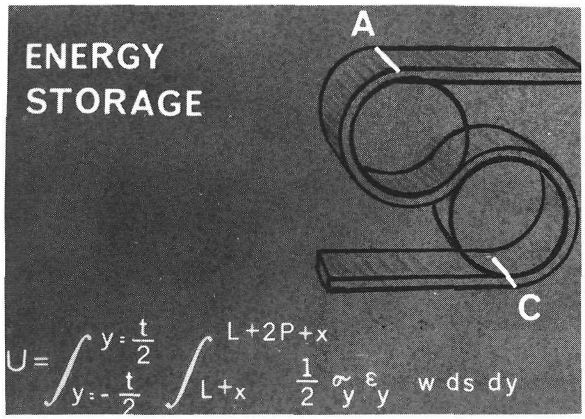

Figure 33

A change in any of the factors in the equation which changes the total elastic strain energy will cause the band to create a force on the roller. Now the way we choose to do this most often is by changing the factor w, or the width of the band.

In Figure 34 we have a condition where everything is in equilibrium between A and C. Since the band is not cut away and is of constant thickness, no forces are created.

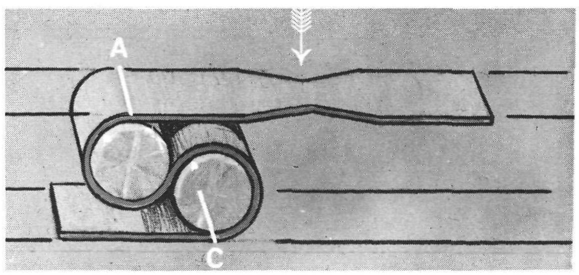

Figure 34

But when the notched-out section of the band (Figure 35) gets to a point over the top roller, then we are going to create a force to the right. The net effect of this in actual operation would be that, if the cluster were moving to the right at a constant velocity and arrived at this notched-out section, the force generated by the band on the rollers would cause the cluster to accelerate to the right. Were it moving in the other direction, the force would cause the cluster to decelerate.

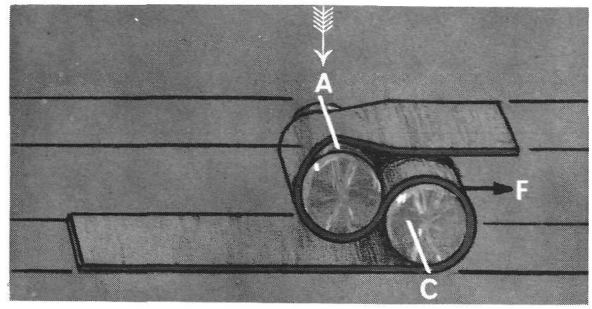

Figure 35

To review (Figure 36), if band widths at A and C are equal, no forces are created; if there is a change in band widths, a force is created.

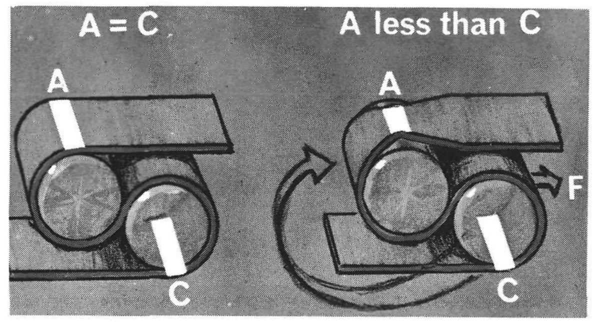

Figure 36

FORCE GENERATION WITH CUTOUTS

There are several ways of configuring a band to get force cutouts. One is an edge cutout, shown earlier; the one we use most often is the interior cutout shown in Figure 37. For a constant force of long duration, you might want to taper a band as shown. I would like to show you a few of the kinds of force deflection curves obtainable by various configurations of the band.

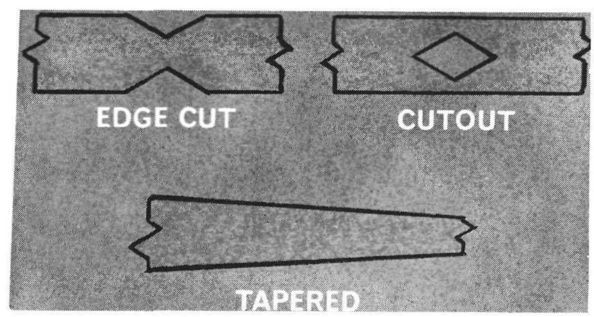

Figure 37

Figure 38 shows a diamond cutout. As the roller cluster first enters the cutout area, a force starts to be created, builds up to a peak at the maximum cutout, and then diminishes. You will note that the force deflection curve is a replica of one half the band cutout.

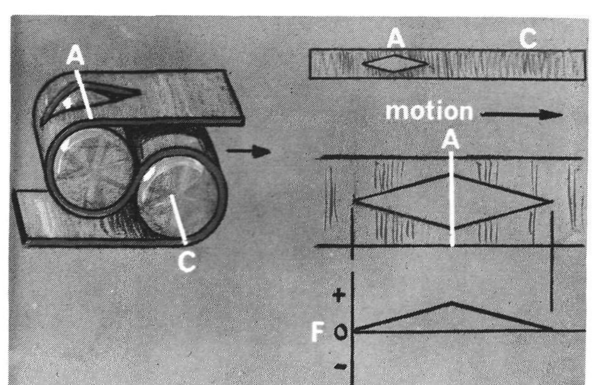

Figure 38

Figure 39 shows a constant force deflection curve, a negative spring constant which is not obtainable by many other ways, and a step-type force deflection curve.

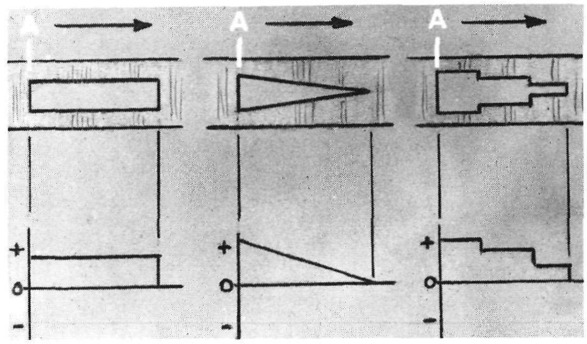

Figure 39

If you want a constant force deflection curve (a constant force for long periods of time), you can taper a band and use it under both rollers simultaneously, as shown in Figure 40.

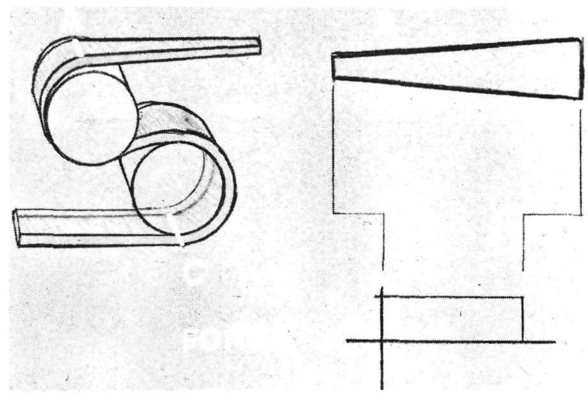

Figure 40

You can also use a cutout under both rollers to provide some unique force deflection curves as shown in Figure 41.

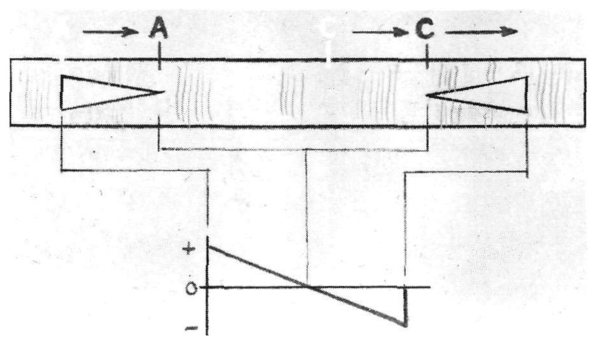

Figure 41

Indeed, you can get all kinds of force deflection curves, depending on how you configure the cutouts, even very elaborate ones as shown in Figure 42.

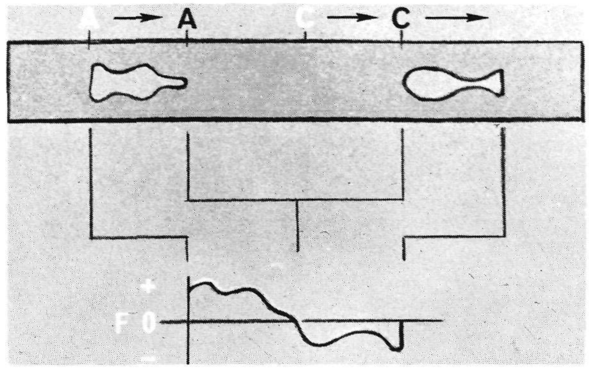

Figure 42

FORCE GENERATION ANALYSIS

The forces generated by the band are more or less illustrated by the equation shown in Figure 43, which is generally correct although it varies somewhat with the looseness or tightness of the geometry. The force generated by the band is equal to the modulus of elasticity of the band material, times the thickness cubed of the band, times the difference in width of the band at points A and C over six times the diameter of the roller plus the thickness of the band squared. A very important factor is the thickness of the band, since it is a cubed factor. You must therefore make sure that your bands are of a constant thickness or you are going to get wide variations in forces.

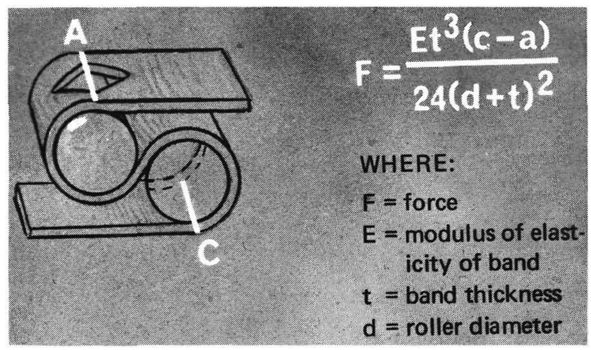

Figure 43

The chart in Figure 44 was drawn up to show the magnitude of the forces obtainable. In our designs we are working with roller diameters of about 1/4 inch and band thicknesses of about 1 mil. For those dimensions, using a stainless-steel band, we can get about 0.14 ounce of force. With a beryllium-copper band, about 0.36 ounce. But notice as you go down the table and get into the larger configurations, up to 2-inch roller sizes and 8-mil bands, that substantial forces can be generated--up to 36 ounces for stainless steel and 92 ounces for beryllium-copper.

ROLLER DIA.	(a - b)	STEEL MAX.BAND THICK.	STEEL F (OZ.)	COPPER MAX.BAND THICK.	COPPER F (OZ.)
.25	.100	.0010	.14	.0017	.36
	.400		.56		1.45
.50	.200	.0021	.56	.0034	1.45
	.800		2.24		5.80
1.00	.400	.0042	2.24	.0068	5.80
	1.600		8.96		23.22
2.00	.800	.0084	8.96	.0137	23.22
	3.200		35.85		92.87

Figure 44

Figure 45 illustrates something said before about the thickness of the band. On an Instron machine we get noise on the force-deflection trace, evidently because the band is not of uniform thickness and thus is responsible for the varying force.

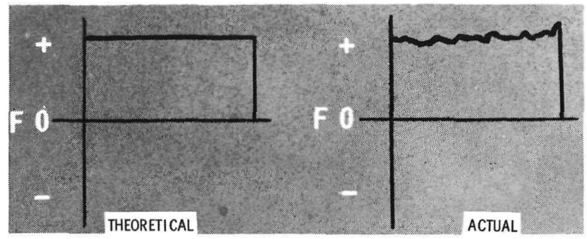

Figure 45

FORCE GENERATION BY PREFORMING

Another way of generating forces with the geometry is to preform the band (Figure 46), in which case we do not change the width of the band, but rather its stress and strain. Shown is the type of force-deflection curve you might get out of a preformed band, but in our experience it has been most difficult to preform bands as opposed to using cutouts in the band to generate forces.

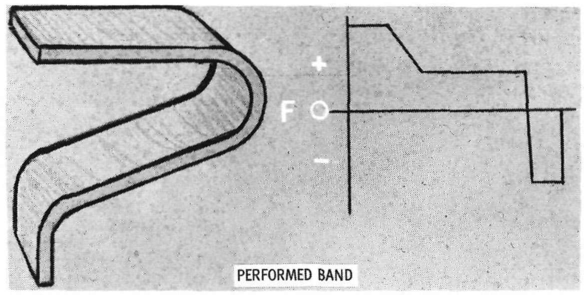

Figure 46

DESIGN APPLICATIONS

Now let me present a few additional rolamite features that can be used in design. If you want to maintain a constant tension on the band, you might want to attach a constant force spring to the band at one end (Figure 47). Or, you might pull off a tongue and put a spring on it. A yoke may be attached to one of the rollers as shown, or a pulley-type arrangement can be designed. Also shown are tabs on the band which are usable for electrical contacting or for latching. Additional rollers in multiples of two and of varying sizes may be used to make up a cluster. They appear to work just as freely as if you had only two.

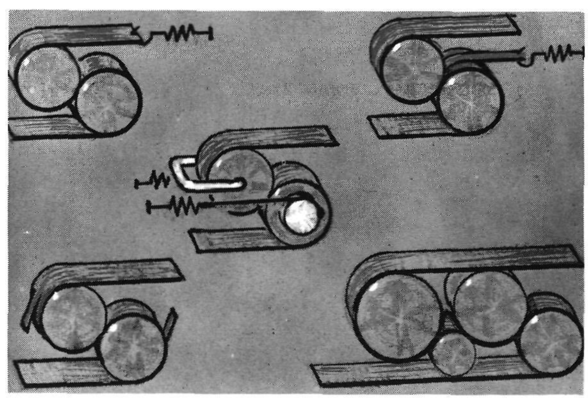

Figure 47

Figure 48 illustrates a rotary bearing which we think has some potential but requires a fair amount of development work. A model made by Technar seems to work quite well. We do worry about two things, however. One is the band: if you get up to very high speeds, you are going to have metallurgical problems as these thin foils will not stand the loads. There is also a problem in retaining the cluster without introducing some friction. Sandia has done very little with the rotary configuration.

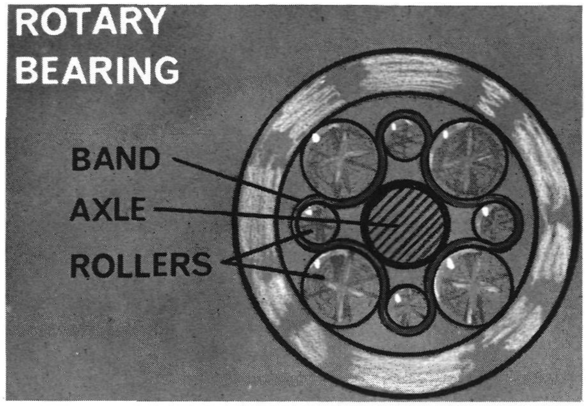

Figure 48

Figure 49 illustrates why we think rolamite can make good electrical contacts. Shown is a band used as a conductor. The tab on the band mates with the contact to complete an electrical circuit. Rolamite offers two unique and very important advantages in making electrical contacts. When the cluster scrubs across the contact it provides an excellent wiping action, and when it rams home it furnishes tremendous contact forces.

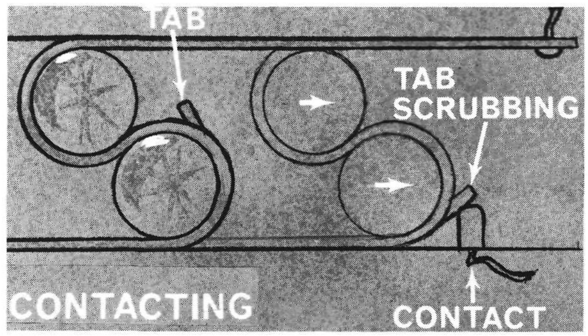

Figure 49

Figure 50 merely illustrates a preformed band, showing that you can carry a number of electrical conductors in a laminated band.

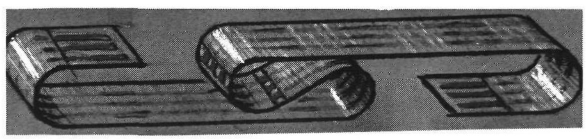

Figure 50

SUBFUNCTION APPLICATIONS

Figures 51, 52, and 53 are a listing of sub-functions that rolamite can perform. If you see some you are interested in, I am sure our panel of experts tomorrow can tell you how to accomplish these functions with rolamite.

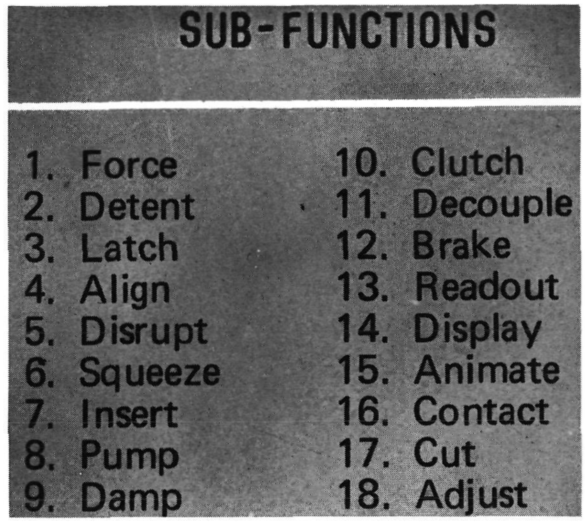

Figure 51

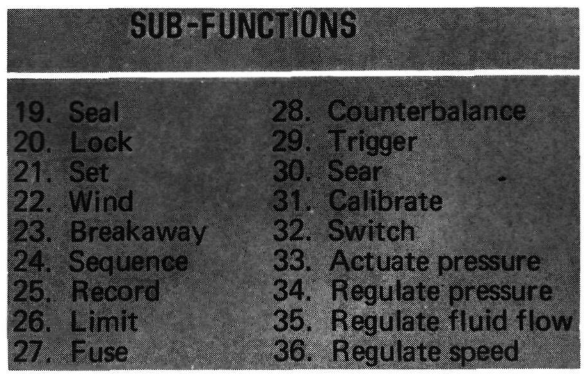

Figure 52

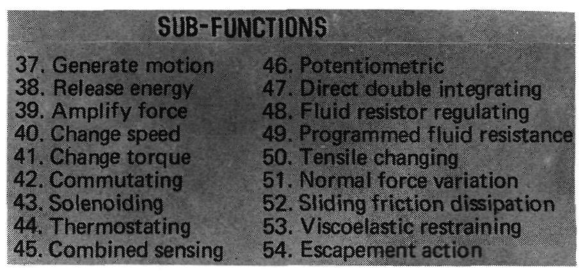

Figure 53

The next series of slides illustrate a few of the functions on the previous lists. Figure 54 shows how you can make an adjustable detent by merely changing the distance that you allow the cluster to fall, into the slot which is controlled by a thumb screw.

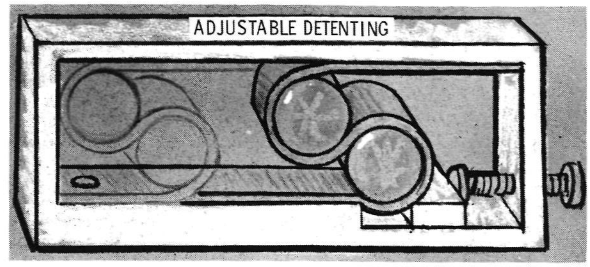

Figure 54

Figure 55 shows an energy-level detenting scheme wherein a certain amount of energy is required for a specific displacement of the cluster and a larger amount for completion of travel.

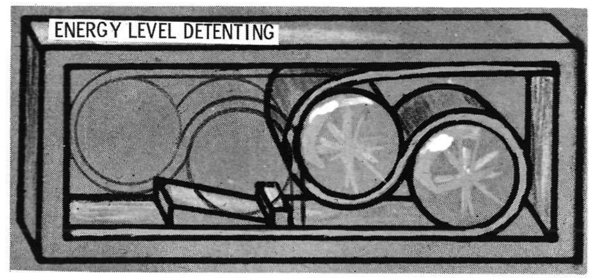

Figure 55

In Figure 56 the cluster moves to the left and, as it comes to the end of the travel, it will snap into position and release large amounts of energy.

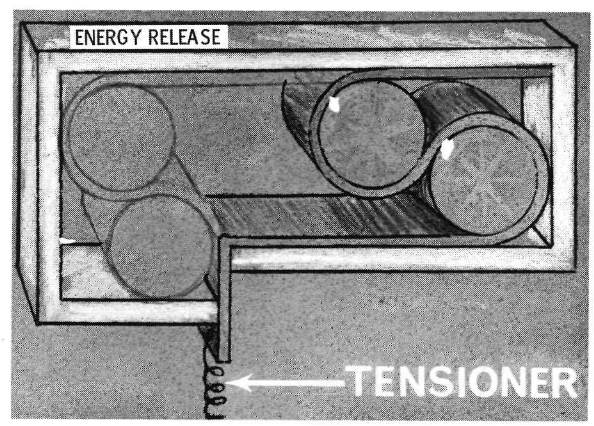

Figure 56

External pumping (Figure 57) can be accomplished by moving the cluster and pumping a fluid or gas contained in the device to the outside.

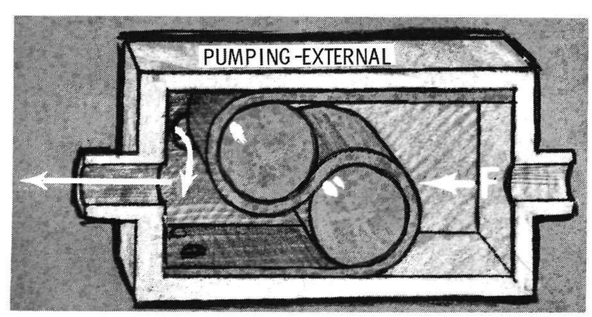

Figure 57

Internal pumping (Figure 58) is an application of rolamite used at Sandia because of our interest in g-second measuring devices. We fill the unit with silicone fluids and, with *properly designed orifices, pump them from* one chamber to the other. Orificing by the sides of the rollers is possible.

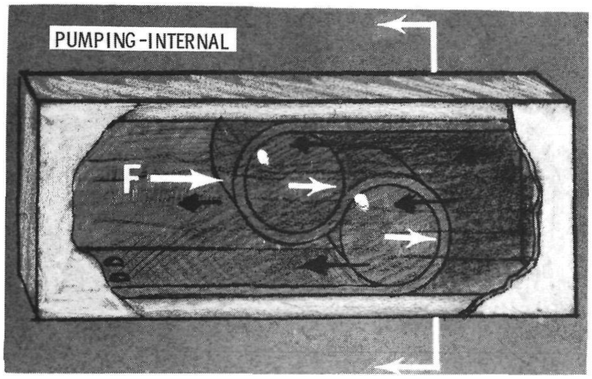

Figure 58

However, we have to maintain very close clearances between the rollers and the outside cases (Figure 59). For gases, we try to keep this clearance between 0.2 to 1.0 mil, and for liquids from 0.5 to 4.0 mils.

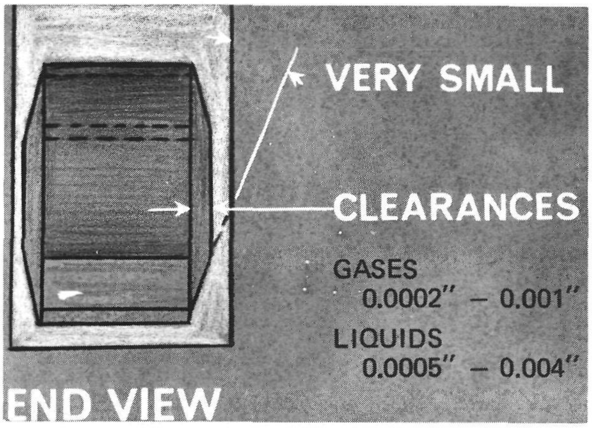

Figure 59

Aligning and disrupting (Figure 60) for ordnance work may be a useful application. If you want to interrupt an explosive train or make an explosive train, you can put the missing link in one of the rollers.

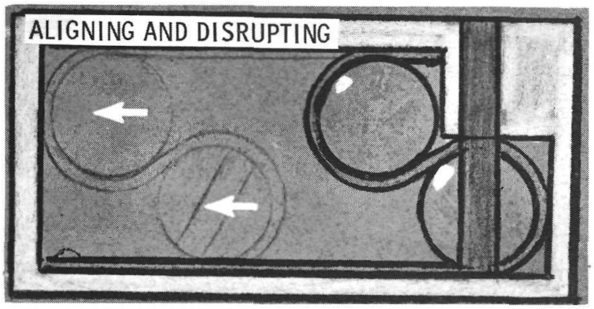

Figure 60

Figure 61 illustrates how you might use rolamite as a valve. With proper design you can get tremendous normal forces for providing a good valve seat.

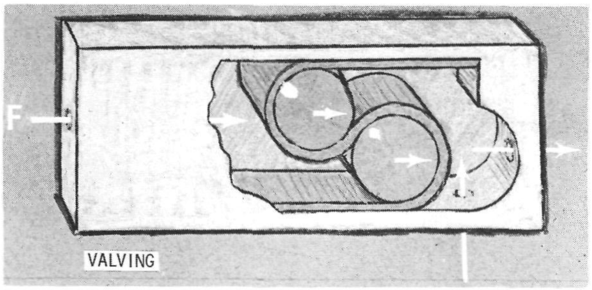

Figure 61

Breaking is illustrated in Figure 62. If you have some sort of frangible vial of toxic gas or liquid you can break it under certain conditions and release its contents. You might encase it between two rollers so that a force applied to the rollers would break the vial.

Figure 62

Latching (Figure 63) can be performed very simply by designing a tab on the band. When it comes to the end of the travel, the tab rolls up on the ledge, providing a latching action.

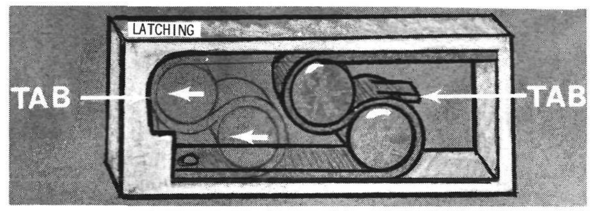

Figure 63

Wedging (Figure 64) can be done in any number of ways; e.g., by putting wedges on the guide surface or on the band.

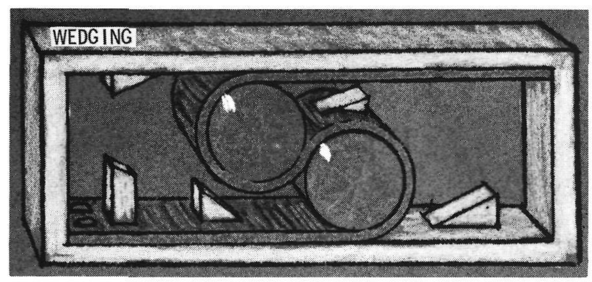

Figure 64

Figure 65 illustrates a simple brake. As you move the cluster, a braking bar contacts the case and causes the cluster to come to a slow stop.

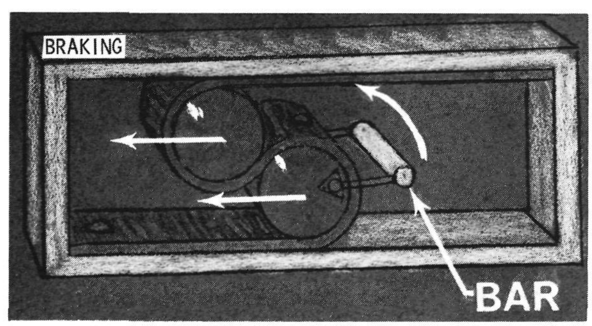

Figure 65

Figure 66 shows a decoupling scheme. If you have a flywheel connected to one of the rollers that you want to decouple at the end of the travel, you let the band expand into the cutout and release the roller from the band, letting the flywheel decouple and come to a slow stop.

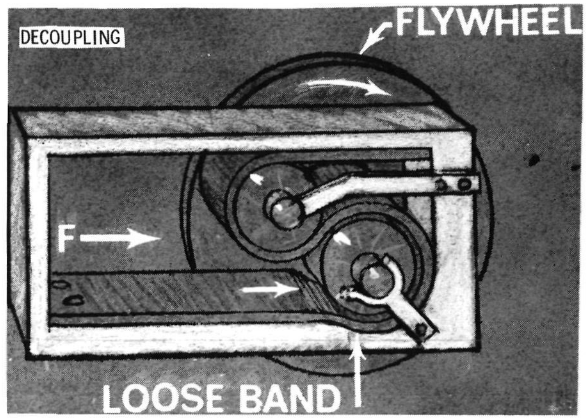

Figure 66

If you are interested in linear speed changing (Figure 67), rolamite is rather unique in that you can get tremendous ratios by using large differences in roller diameters, probably more than you can get in any single stage of conventional gearing. Of course, you are limited by the band-thickness/roller-diameter compatibility problem.

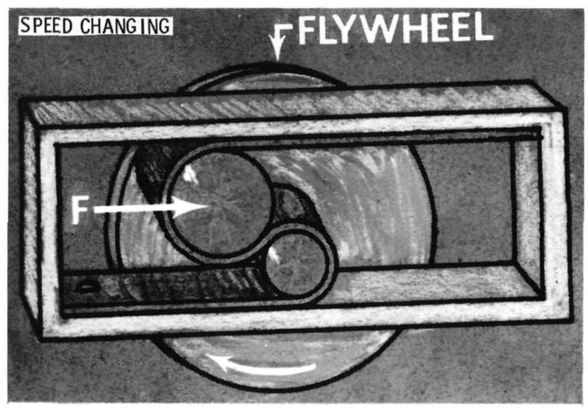

Figure 67

By using bimetallic bands, constructed of low- and high-expansion materials (Figure 68), the cluster can be made to respond sensitively to temperature changes.

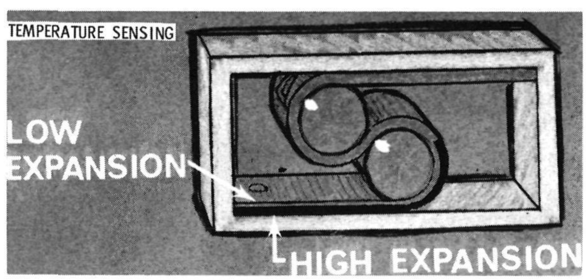

Figure 68